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66. DETECTING ILLICIT TRAFFICKING

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INTRODUCTION

In today's society acts of terrorism must involve in some stages the illicit trafficking either of explosives, chemical agents, nuclear materials and/or humans. Therefore the society must rely on the anti-trafficking infrastructure, which encompasses responsible authorities: their personnel and adequate instrumental base.

Modern personnel, parcel, vehicle and cargo inspection systems are non-invasive imaging techniques based on the use of nuclear analytical techniques. The inspection systems are using penetrating radiations (neutrons, gamma and x-rays) in the scanning geometry, with the detection of transmitted or radiation produced in investigated sample.

Explosives and chemical agents detection systems are based on the fact that the problem of identification can be reduced to the problem of measurement of elemental concentrations. Different nuclear analytical techniques could be used for this purpose, however the use of neutrons has some specific advantages. Of special interest is the design and functioning of a transportable gamma-ray system for inspecting cargo vehicles and containers for contraband, explosives, weapons or humans.

The risk of nuclear terrorism carried out by sub-national groups is also considered not only in construction and/or use of nuclear device, but also in possible radioactive contamination of large urban areas. An ever-increasing danger of terrorist actions involving theft and unauthorized proliferation of fissionable and radioactive materials makes it imperative to develop and manifacture reliable equipment for detection of explosive, fissionable and radioactive materials concealed inside various objects and hand luggage.

MATERIALS TO BE CONTROLLED

The list of materials, which are subject to inspection with the aim of reducing the acts of terrorism, includes explosives, narcotics, chemical weapons, hazardous chemicals and radioactive materials. To this we should add also illicit trafficking with human beings.

Explosives: The first explosive known was gunpowder, also called black powder. In use by the 13th century, it was the only explosive known for several hundred years. Nitrocellulose and nitroglycerin, both discovered in 1846, were the first modern explosives. Since then nitrates, nitro compounds, fulminates, and azides have been the chief explosive compounds used alone or in mixtures with fuels or other agents. Today we have a list of some 100 explosive materials. However, the most often used explosives are: Trinitrotoluene (TNT), Trinitrophenylmethylnitramine (Tetryl), Pentaerythritoltetranitrate (PETN), Ciklotrimetilentrinitramin (RDX), Tetrytol, and Hexatol; their elemental compositions are shown in Table 1.

Drugs: Similarly, Table 2 shows the atomic composition of some chemical weapons agents. Old generation chemical agents are chlorine based, while new generation are phosphorous based.

Fissionable and radioactive materials: There is a real risk that sub-national groups will in the future acquire fissile material – particularly plutonium – and construct a nuclear explosive. Equally disturbing, and perhaps more likely, is the possibility that plutonium may be acquired by a group who will threaten to disperse it, by an explosion, and radioactively contaminate a large urban area.

These risks exist because: a large amount of civilian plutonium is being produced and stockpiled; a relatively small amount of such plutonium is needed for a nuclear explosive; the technical information required to fabricate a nuclear device is available in the open literature; and only a small number of competent people are necessary to fabricate a primitive nuclear device.

The design of a "first generation" nuclear weapon, such as the bomb that destroyed Nagasaki in 1945, is no longer secret [1], a competent nuclear physicist can find the relevant information in the open literature (see also ref. [2] and [3]). Several types of these devices are possible: (i) Gun type and (ii) Implosive types. Implosion seems to be a favourite "first try". For example Iraq's importation of explosives and electronics suggested development of an implosion-type bomb. For this last type high-explosive charges are required. The amount of high explosive used in a fission weapon has decreased considerably since 1945 – from about 500 kg to about 15 kg or less. Explosive lenses and detonators adequate for an implosion-type atomic bomb are commercially available [4].

Although a sub-national group could choose to use either plutonium or highly enriched uranium as the fissionable material for nuclear explosives, plutonium is increasingly, the more likely option. A sub-national group that in the future decides to manufacture a nuclear explosive is, therefore, most likely to try to steal or to buy plutonium.

INSPECTION

Modern personnel, parcel, vehicle and cargo inspection systems are non-invasive imaging techniques based on the use of nuclear analytical techniques. The inspection systems are using penetrating radiations (neutrons, gamma and x-rays) in the scanning geometry, with the detection of transmitted or radiation produced in investigated sample.

Explosives and chemical agents detection systems are based on the fact that the problem of explosive identification can be reduced to the problem of measurement of elemental concentrations. Different nuclear analytical techniques could be used for this purpose. Of special interest is the design and functioning of a transportable gamma-ray system for inspecting cargo vehicles and containers for contraband, explosives, weapons or humans and the use of neutrons.

NUCLEAR MATERIAL MONITORING

Portal monitoring for the movement of nuclear material is a common practice. Pedestrian and vehicle portal monitoring for Special Nuclear Materials (SNM) can be used for entrances and exits from nuclear facilities. When gamma rays from the SNM interact with the plastic scintilator, light pulses are generated. The light pulses are amplified and compared with the background radiation level. An alarm sounds if an event is statistically different from the background.

The aim of the control of passengers and goods for radiation at customs is to prevent the illegal or unintentional import and export of radioactive material. Automatic pedestrian and vehicle portal monitors have been used since the 1970s at US nuclear facilities to prevent the unauthorized movement of SNM. There are several recognized manufacturers of these equipment items. Of special interest are Vehicle Portal Monitors, which normally consist of two, self contained, weather resistant pillars placed on either side of the entrance to be protected. Each pillar contains two plastic scintillator detectors, an occupancy detector, and an amplifier/controller. The master pillar also has a battery and power supply. These monitors are designed to automatically scan vehicular traffic without the need for frequent calibration. They are intended for applications where the relatively low energy emissions from ^{235}U and ^{239}Pu are the main concern. They are currently in use in installations such as uranium

enrichment plants, weapons manufacturing and storage plants, nuclear laboratories, and nuclear waste disposal and storage sites where protection of SNM is essential. Development of a combined device for the detection of unauthorizesed transportation of explosive, fissionable and radioactive materials are in progress (RATEC. St. Petersburg, Russian Federation).

It is a reasonable assumption that only State authorities could be responsible for detecting and responding to illicit nuclear trafficking activities on their territory. However, no clear minimum requirements exist on what measures are necessary to meet this responsibility [5,6].

DETECTION
The use of X-rays

The usual instruments, which are using x-rays, are based on the measurement of x-ray intensity reduction while passing through the investigated object. For a given x-ray energy the adsorption of x-rays depend on the object thickness and its average atomic number, Z. In the case of x-ray energy above 100 keV the adsorption depends primarily on material density, independently of its atomic number. Therefore the materials with higher density absorb more x-rays what results in the darker image. This is the principle used for the detection of arms in suitcases in airports. However, using this approach one cannot detect explosive device, which is in the luggage together with the high-density object [7].

In order to increase the probability of explosive detection one needs to increase the method's sensitivity with respect to the material atomic number. This could be achieved with excitation of the same sample with another (smaller) x-ray energy. For smaller x-ray energies the absorption depends on both atomic number and thickness. In such a way one may distinguish iron, which has a Z_{ef} =25 from the explosive having a Z_{ef} =7. The combination of two x-ray energies (system with double energy) allows identification of explosives having high density and small Z. There are several systems with dual energy on the market (American Science and Engineering, EG&G Astrophysics, Vivid Technologies and SAIC). These instruments are providing the ability to quickly and efficiently search for weapons, drugs, and contraband in areas too difficult or time-consuming to search by hand. In addition they can be used to investigate suspicious packages in a mailroom scenario, as well as point-of-entry examination of personal belongings. Instruments can be mounted on full-size bomb disposal robots, as well as on standard photographic tripods.

Another device of interst is SAIC's CDS-2002i contraband detector providing X-Ray vision for law enforcement professionals. The CDS-2002i is an improved portable contraband detection system used to detect contraband hidden within areas such as automobile tires, doors, fenders, bumpers, fuel tanks as well as aircraft structures, boat hulls and building walls. The CDS-2002i is a lightweight, hand-held system, which utilizes a microprocessor, a self-contained low-level radioactive source (100 μCi of [133]Ba), and a sensitive detector to measure backscatter through solid surfaces. As surfaces are scanned, concealed objects and materials including weapons, narcotics, alcohol and explosives reflect the low level radiation, which is measured by the very sensitive detector.

Gamma ray technology

Gamma ray technology has proven itself to be fast, reliable, effective and inexpensive way to identify and deter the contraband transportation business. Because they use commonly available isotopic sources, gamma-ray systems are able to provide greater inspection capability while eliminating the need for large, costly, high-maintenance x-ray sources and accelerators. Gamma rays have a much higher effective energy than commonly used x-ray

sources. This higher energy translates to superior penetration and the single-energy output of the source results in a sharper image. Commonly used sources are ^{60}Co (E=1.3 MeV) and ^{137}Cs (E=662 keV).

SAIC, San Diego, California has put on the market several gamma ray based systems, the best known is called VACIS (Vehicle and Cargo inspection System). There are four main components to any such inspection system: the source, the detectors, the computer and the infrastructure. In terms of speed and throughput, a gamma-ray system is the only practical method of achieving 100% container inspection. While comparable x-ray based systems take only minutes to scan a container, the entire inspection cycle time can be 7-15 minutes. This translates to less than 100 vehicles per day. In contrast, gamma-ray based systems can scan a standard 40-foot container in as little as a few seconds, with an inspection cycle time of less than a minute. This leaves the flow of commerce unhindered by the inspection process, an important consideration for customers.

Neutron sensor

Nuclear techniques have been applied in the detection of hidden explosives for a number of years [8]. Basically, they work on the principle that nuclei of the chemical elements in the investigated material can be bombarded by penetrating nuclear radiation (mainly neutrons). As results of the bombardment, nuclear reactions occur and a variety of nuclear particles, gamma and x-ray radiation is emitted, specific for each element in the bombarded material

The problem of material (explosive, drugs, chemicals, etc.) identification can be reduced to the problem of measuring elemental concentrations. Nuclear reactions induced by neutrons that can be used for detection of chemical elements, their concentrations, and concentration ratios or multielemental maps, within the explosives are listed in the following Table 3.

In this respect, several nuclear systems have been proposed, developed and tested so far. All efforts performed so far can be grouped with respect to the type of neutron source and the type of detected radiation and detector type. The neutron source can be either an accelerator: sealed tube or pumped system; the detected radiation is either gamma radiation or scattered neutrons.

The use of radioactive sources:

Usually two types of sources are used: ^{252}Cf that decays by spontaneous fission and Be(α,n) sources, where as an α emitter americium, or plutonium, is used. The source of ^{252}Cf is preferred because of its low specific activity (low yield of gamma rays) and known shape of neutron spectrum. On other hand, Be(α,n) source delivers higher energy neutrons as well as a gamma ray of the 4.43 MeV energy, which is the result of decay of an excited state in ^{12}C.

Detection of gamma rays: The use of ^{252}Cf source in an apparatus designed to detect the presence of explosives was the first method tried [8]. In this case the outgoing gamma rays were detected. In this work the ^{252}Cf source delivered 2×10^6 n/s/microgram. When neutrons hit the material investigated they loose energy by inelastic scattering. Neutrons with the energy less then 0.025 eV (thermal neutrons) are captured by nitrogen nuclei, which afterwards emit gamma ray of the 10.83 MeV energy, being the signature of nitrogen presence. Since the number of emitted gamma rays is proportional to nitrogen concentration in the sample, it is possible to quantify the amount of nitrogen in the sample. This method has resulted in an apparatus, which was installed on several airports immediately after the Pan Am flight 103 tragedies. One of the drawbacks of this method was nonspecifity. Starting the year 1992 the US Army is using so called PINS (Portable Isotopic – Neutron Chemical Assay

System) for the identification of chemical shells and containers with chemicals (made by ORTEC, USA). In this system the gamma ray spectra are measured by high resolution Ge spectrometer. The source used is 5 micrograms (or 99 MBq) of ^{252}Cf: all the system has a weight of some 50 kg. The software determinates the type of material by using intensities and ratios of intensities for the following chemical elements: As, B, C, Ca, Cl, Fe, H, K, Na, P, S, Ti and Zn.

Several systems are described in the literature (ref.14): for small parcel detection (SP-EDS), vehicular detection system (V-EDS), mine detection (M-EDS). SP-EDS utilizes TNA technology for inspection of small parcels like briefcases, postal packages and handbags. SP-EDS can be deployed alone or used as a part of a larger, comprehensive existing security system. For example, the product is proving useful in airports when used inline with traditional X-ray machines. Instead of unpacking a bag, when the X-ray machine detects items of specific shapes, liquids or laptops, the bag is put into the SP-EDS machine to automate the inspection process. X-rays flag the item, then SP-EDS determines whatever it contains anything of concern. Similar system is also available frm RATEC and some other manufacturers. The other system, V-EDS, also based on TNA, is usually mount4ed in a vehicle, moved alongside parked cars and trucks, scan the contents of these vehicles and instantly detects explosives. It can be installed at the in trances of vulnerable parking areas.

Neutron detection: For detection of explosives a different type of sensor can be obtained by looking at the low energy neutrons that are back scattered from the soil in presence of large hydrogen content, as is the case in a landmine. This process is certainly less specific compared to the detection of characteristic gamma rays because hydrogen is also contained in the soil moisture. Nevertheless, the presence of material with high hydrogen content can be taken as an indication of an anomaly in the soil, in the same way actually done by other systems as metal detectors or GPR systems [9].

The use of accelerators:

Different types of charged particle accelerators can be used as a neutron source. The accelerators are producing a beam of charged particles, which bombards a suitable target where neutrons are produced via a nuclear reaction. The charged particle beam can be pulsed, and as a consequence the resulting neutron beam can have time dependant shape (see Fig. 1). Neutron beam energy depends on the type of nuclear reaction used in the neutron production as well as the energy of charged particle beam. The small sealed tube neutron generators are of special interest because they could be used in the construction of transportable instruments. The use of accelerators allows more degrees of freedom in device construction.

For a simultaneous detection of several elements, and for an efficient analysis, high-energy neutrons in pulsed mode are required. During one short pulse of 14 MeV neutrons, high energy neutrons are emitted and interact with the material, leading to elastic scattering with prompt emission of characteristic gamma-rays, and also to nuclear reactions with prompt and delayed emission of gamma rays and/or particles, see Fig.3. [10]. During the pulse, it is then possible to detect mainly inelastic scattering and prompt emission from nuclear reactions, with a background at low level from residual activation. System using pulsed fast neutrons and time of flight measurement (PFNA-TOF) is described in the report issued by US Office of National Drug Control Policy [11]. The system is using 8.2 MeV pulsed neutron beam to scan the material in the cargo container. The neutron beam interacts with the atomic nuclei of material in the container: the nuclei excited in the inelastic processes emit gamma rays of the characteristic energies. The measured gamma ray spectrum depends on the elemental composition of the material in the container. The system, which emits the neutrons, also defines their paths. The exact location of the object is additionally

defined by the measurements of time interval between neutron pulse and the detected gamma ray. In order to distinguish drugs (for example cocaine) from the rest of material, the system is measuring the amounts of oxygen and carbon in volume elements (voxels) of the container. The system produces the elemental picture of the whole volume what enables finding of the drug in the hidden locations.

Several systems based on the use of pulsed sealed tube generator have been reported. The investigated object is identified by comparison of its "elemental fingerprint" with the "elemental fingerprints" of number of materials in the library in computer memory. SODERN, in France has studied the possibility for realization of a sensor for gamma ray detection produced either by fast neutron or slow neutron activation [12].

The experimental configuration which should be realized in the new system should include neutron generator used in both continuous and pulsed modes, with detection of gamma rays from neutron inelastic scattering, from thermal neutron capture and from fast or thermal neutron activation.

There is at least one commercial system described in the literature [13] which uses pulsed fast neutron analysis to detect the presence of contrabands and drugs. System for cargo inspection, ACI system, based on PFNA technology, has been designed specifically for the wide range of needs related to cargo inspection. As a vehicle or container pulls through a scanning area, the ACI sends pulses of neutrons that stimulate unique elemental signals from the materials in small segments, voxels. These measurements are used to generate 3D element maps on a computer screen. From there, characteristic elemental signals identify the cargo and pinpoint any suspect material present.

EXPERIMENTAL ARRANGEMENTS

The present experimental arrangement is constructed using an 150 keV deuteron accelerator at the Institute Ruder Boskovic. The accelerator has been modified to be an pulsed 14 MeV neutron source with the possibility of detection of associated alpha from the $d+t \rightarrow \alpha+n$ reaction. A computer-controlled wagon (controlled position and speed) contains an object (which could be a landmine in a soil at the variable depth, or something else like explosive in a suitcase on the conveyer). The detector is planned to be both gamma and neutron detector with the n-γ separation, allowing simultaneous measurements of both gamma and neutron spectra. Geometry of object excitation and radiation detection could be changed according to technique requirements. The recognition software with signatures database will be developed so that the system can recognize a series of materials, which are usually subject to control. Details of experimental set-up are shown in Fig. 2.

NEW DEVELOPMENTS

With modern techniques such as neural-networks, feature extraction, computer vision, statistical and syntactical pattern recognition, anomaly detection, and knowledge discovery, computers have the ability to extract information from multiple sources and identify and track patterns of activity that are inconsistent with "normal" operations. Warning systems can then be activated to alert human operators and recommend actions. These automated decision aids can facilitate such things as intelligent surveillance of areas where normal human monitoring is unsafe, administratively difficult, or economically impractical to meet the challenges of ever increasing interpretation of large amounts of complex data. Research in advanced surveillance and monitoring technologies is producing more fully automated and integrated systems that will be applicable to the requirements of the future. For example the research of Intelligent Computer Vision includes the characterization and recognition of shapes of objects in moving and still images, both real-time and archival. A new algorithmic

framework for image segmentation, object recognition, and image understanding allows an automated system to distinguish human shapes from other objects.

Based upon the normal behavior patterns ascertained through Pattern Recognition, anomalous activities, such as an individual's entry into an area in which he's never been before, may now be identified. Anomalous activities that are detected can be communicated to appropriate security personnel for immediate response or archived for subsequent development of deterrence strategies. The goal is to learn from the data and adapt to changes automatically. Based on learning "normal" activities, the system will alert all anomalies and not just those that have been previously identified. This produces the most reliable and secure anomaly detection capabilities. Los Alamos is working with Motorola Corporation on a joint project to design and develop a digital camera with such advanced surveillance features.

SUMMARY

Modern personnel, parcel, vehicle and cargo inspection systems are non-invasive imaging techniques based on the use of nuclear analytical techniques. The inspection systems are using penetrating radiations (neutrons, gamma and x-rays) in the scanning geometry, with the detection of transmitted or radiation produced in investigated sample.

Explosives and chemical agents detection systems are based on the fact that the problem of explosive identification can be reduced to the problem of measurement of elemental concentrations. Different nuclear analytical techniques could be used for this purpose. Preventing nuclear smuggling is crucial to preserving a world free of nuclear terrorism.

Today's technology allows establishment of an effective system for prevention of illicit trafficking of either explosives, drugs, chemical agents, nuclear material or humans.

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KEY WORDS

Illicit trafficking, explosives, drugs, nuclear materials, x-rays, gamma rays, neutrons.
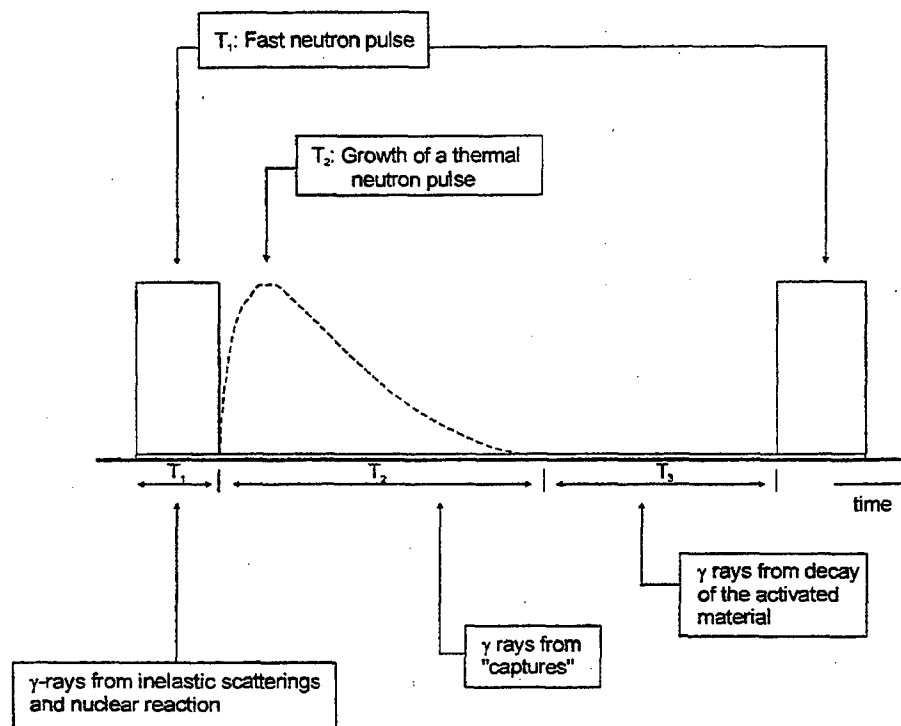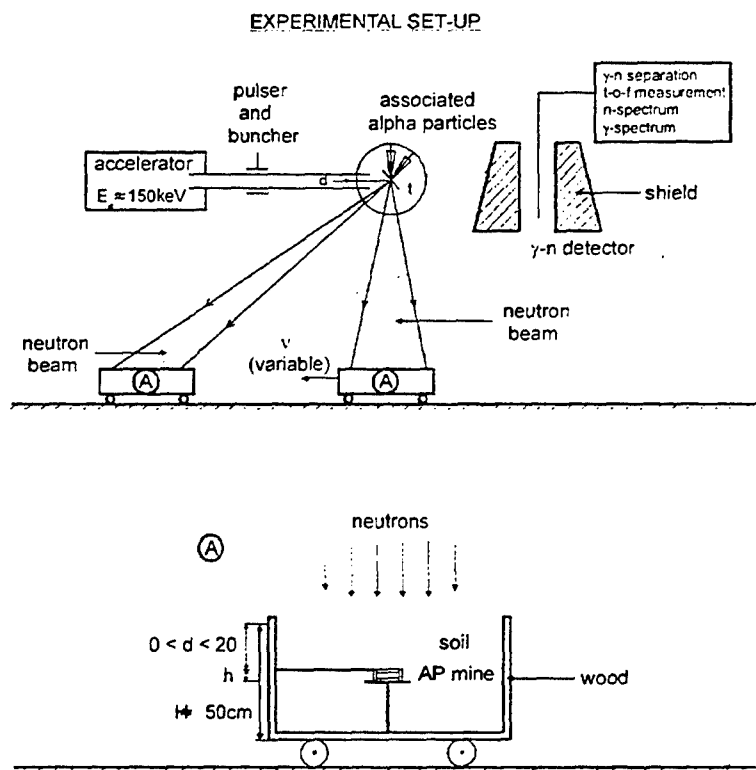

Fig 1.
Time structure of neutron beam and resulting radiation from the investigated object

pulser
and
buncher

associated
alpha particles

γ-n separation
t-o-f measurement
n-spectrum
γ-spectrum

accelerator
E ≈150keV

d

t

shield

γ-n detector

neutron
beam

neutron
beam

neutron
beam

v
(variable)

(A)

(A)

(A)

neutrons

$0 < d < 20$

soil

h

AP mine

wood

50cm

soil: typical soils from the minefields,
geochemical, physical end pedological characteristics

AP mine: typical mines (several) found in Croatia

Fig 2. Experimental set-up.

Table 1. Nitrocompound Explosives.

Formula	Molar Mass	Density (g/cm^3)	Name	Vapour Pressure (rel./Torr at 25°C)	Detonation speed (m/s)
$C_7H_5N_3O_6$	227.1	1.65	TNT	7.7 ppb / 5.8×10^{-6}	6.94
$C_7H_5N_5O_8$	287.2	1.73	Tetryl	7.5 ppt / 5.7×10^{-9}	7.65
$C_5H_8N_4O_{12}$	316.0	1.78	PETN	18 ppt / 1.4×10^{-8}	8.31
$C_3H_6N_3O_6$	296.0	1.83	RDX	6.0 ppt / 4.6×10^{-9}	8.64
$C_3H_5N_3O_9$	227.1	1.59	Nitroglycerin	0.41 ppm / 3.1×10^{-4}	7.6
$C_4H_8N_8O_8$	296.2	1.96	Octogene	3.95 ppt / 3×10^{-9}	9.1

Table 2. Elementary composition of some CW agents (atom number/molecule).

Agent	Cl	P	As	S	F	O	N	C	H
S-Mustard (HD)	2			1				4	8
N-Mustard (HN)	3						1	6	12
Yperite	3						1	6	12
Lewisite (L1)	3		1					2	2
Lewisite (L2)	3		1					4	4
Lewisite (L3)	3		1					6	6
Tabun (GA)		1				2	2	5	11
Sarin (GB)		1			1	2		4	10
Amiton(VX)		1		1		2	1	11	26
Clark I (DA)	1		1					12	10
Clark II (DC)			1				1	13	10
Soman (GD)		1			1	2		7	16
VX		1		1		2	1	11	26

Table 3. Neutron induced nuclear reactions which can be used for elemental concentrations determination.

c	Reactions	Neutron energy	Reaction type
H	$^{1}H(n,\Box)^{2}H$	thermal	prompt
C	$^{12}C(n,n'\Box)^{12}C$	5 MeV and up	prompt
N	$^{14}N(n,\Box)^{15}N$	thermal	prompt
N	$^{14}N(n,n'\Box)^{14}N$	3 MeV and up	prompt
N	$^{14}N(n,2n)^{13}N$	14 MeV	activ.,9.9 min
O	$^{16}O(n,n'\Box)^{16}O$	7 MeV and up	prompt
O	$^{16}O(n,p)^{16}N$	9 MeV and up	activ.,7.13 s
Cl	$^{35}Cl(n,\Box)^{36}Cl$	thermal	prompt
Cl	$^{35}Cl(n,n'\Box)^{35}Cl$	3 MeV and up	prompt
Cl	$^{37}Cl(n,p)^{37}S$	14 MeV	activ.,4.9 min